FORENSIC ENGINEERING ANALYSIS OF A COMBUSTION TURBINE COMPRESSOR BLADE FAILURE

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PROBLEM STATEMENT

During a scheduled outage of a combustion turbine at a utility in Oahu, HI, it was found that the compressor rotary and stationary blading presented severe mechanical damage. No abnormal vibrations were noted prior to the outage. The unit is rated at 45 MW, had been in intermittent service for 11 years for about 11,000 hrs when normally these units average 8,000 hrs per year.

Two stationary blades from the first stage had failed and came apart at the blade root. These two failed blades were pushed through all the compressor blade stages down stream inducing severe damage on all the stationary and rotary blades of the compressor.

Wet fluorescent magnetic particle testing (WFMT) linear indications were detected in several other blades in stage one of the compressor stationary blading. These indications were located away from the mechanical damage caused by the failed blades.

A forensic engineering analysis was performed to determine the root cause of the failure. The main tasks of the analysis consisted of nondestructive testing, metallurgical examination, and finite element stress analysis.
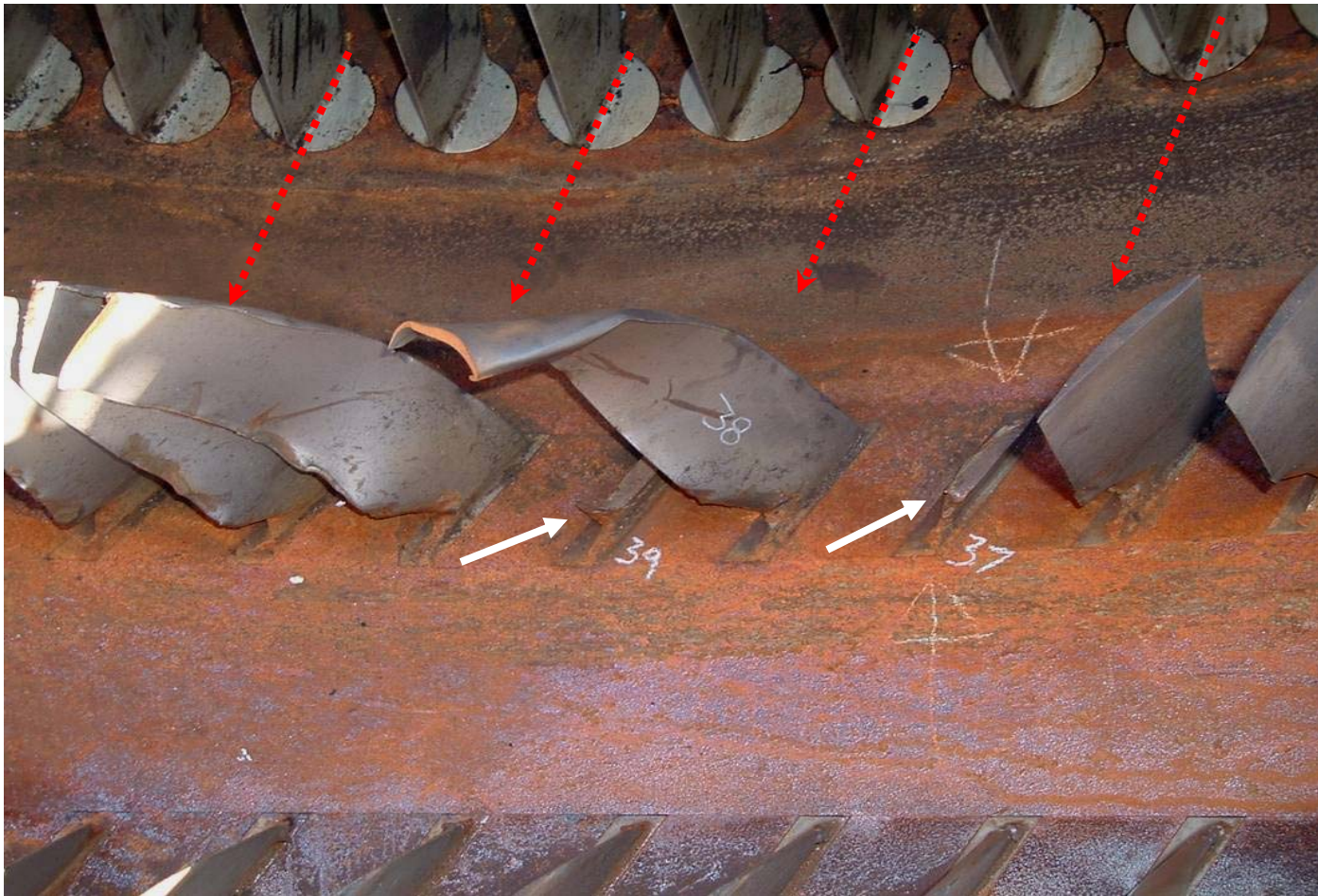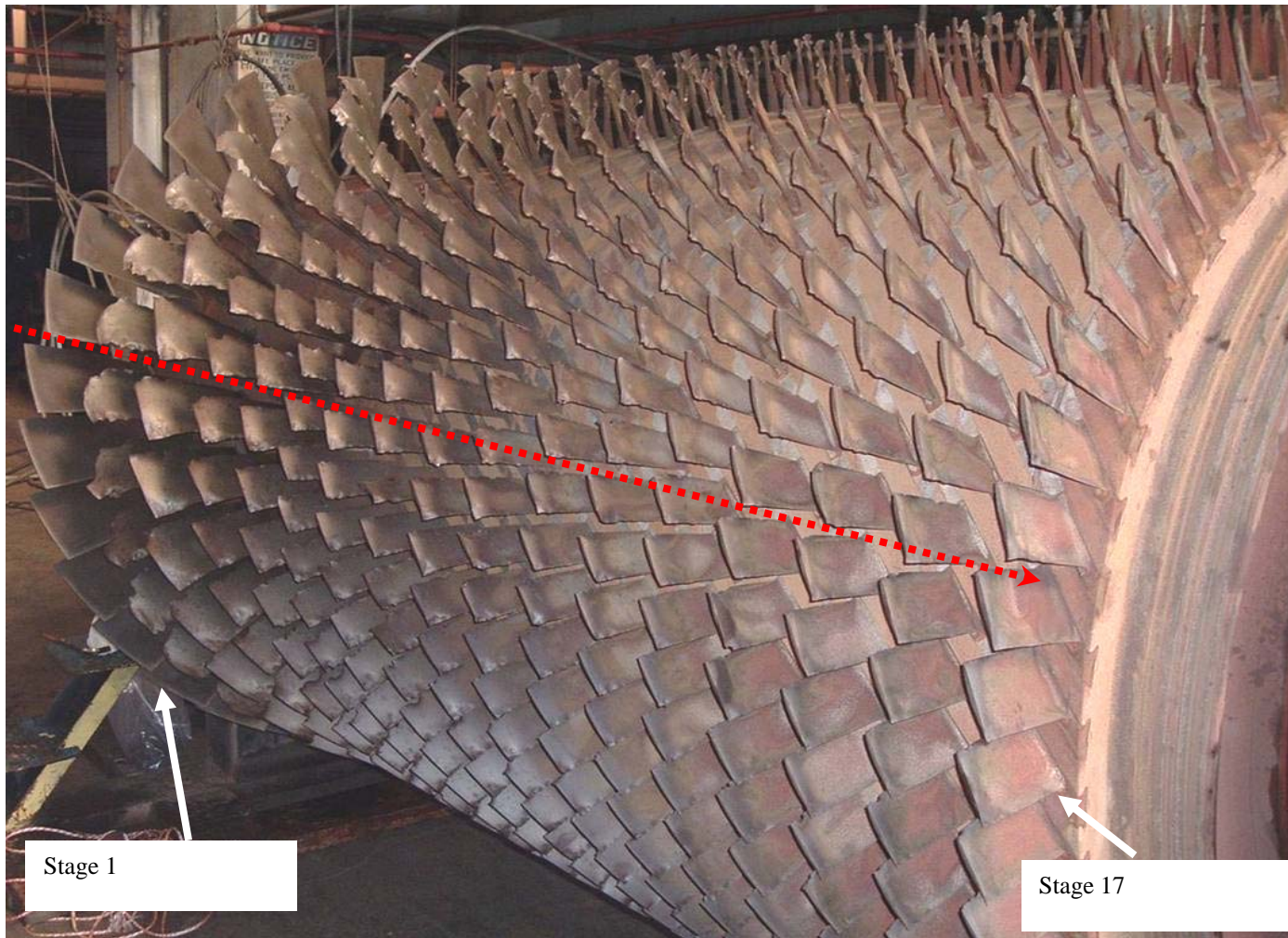
Photo of the compressor stationary first stage failed blades. White arrows point at two out of five failed blades. Red dotted arrows show air inlet flow direction
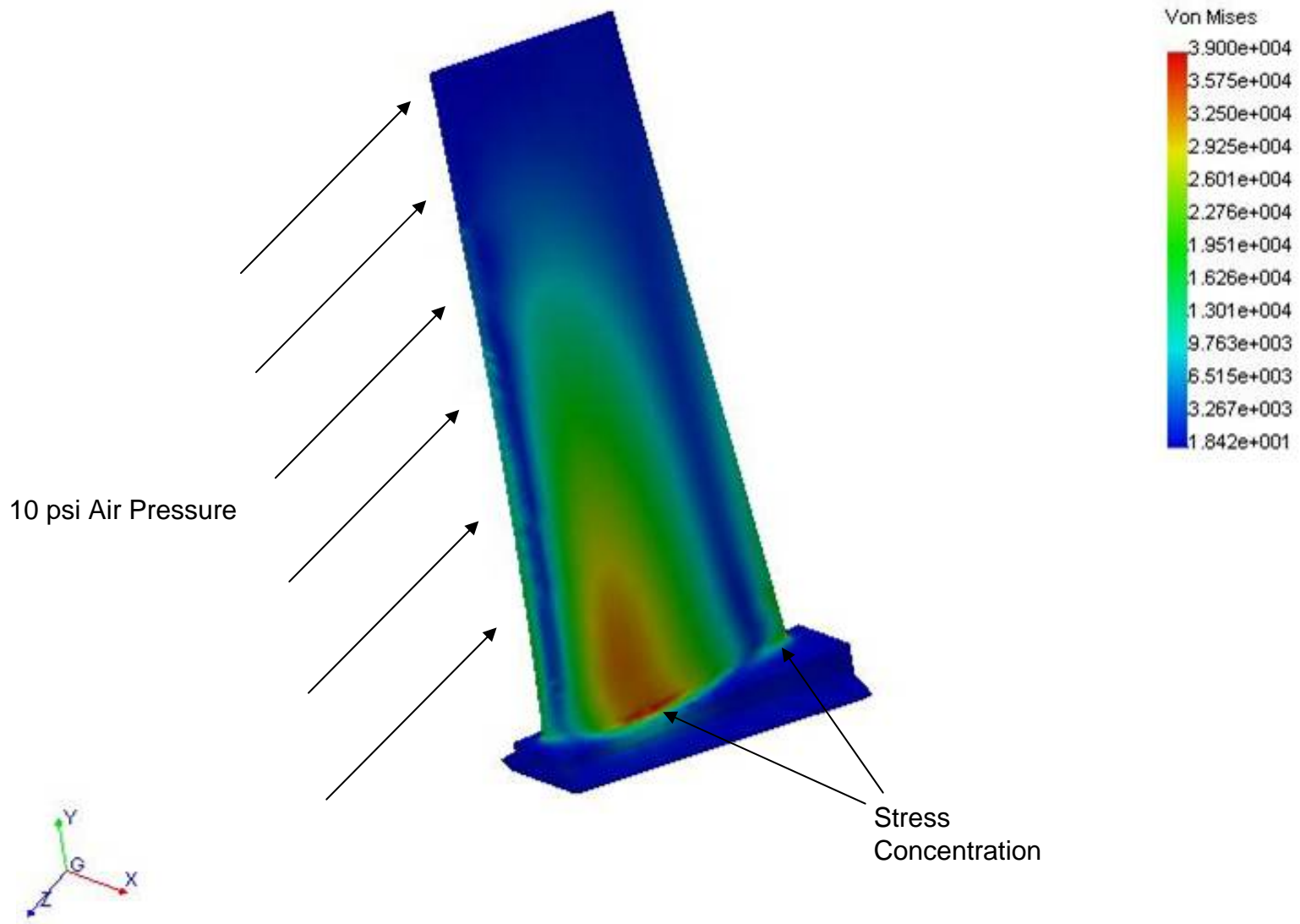
Severe mechanical damage observed on the compressor rotor blading caused by the stationary failed blades. Red dotted arrow shows air inlet flow direction from stage 1 toward stage 17.

Photo of compressor stationary blading (lower half) showing a piece of a blade severed from the first stage failed blades
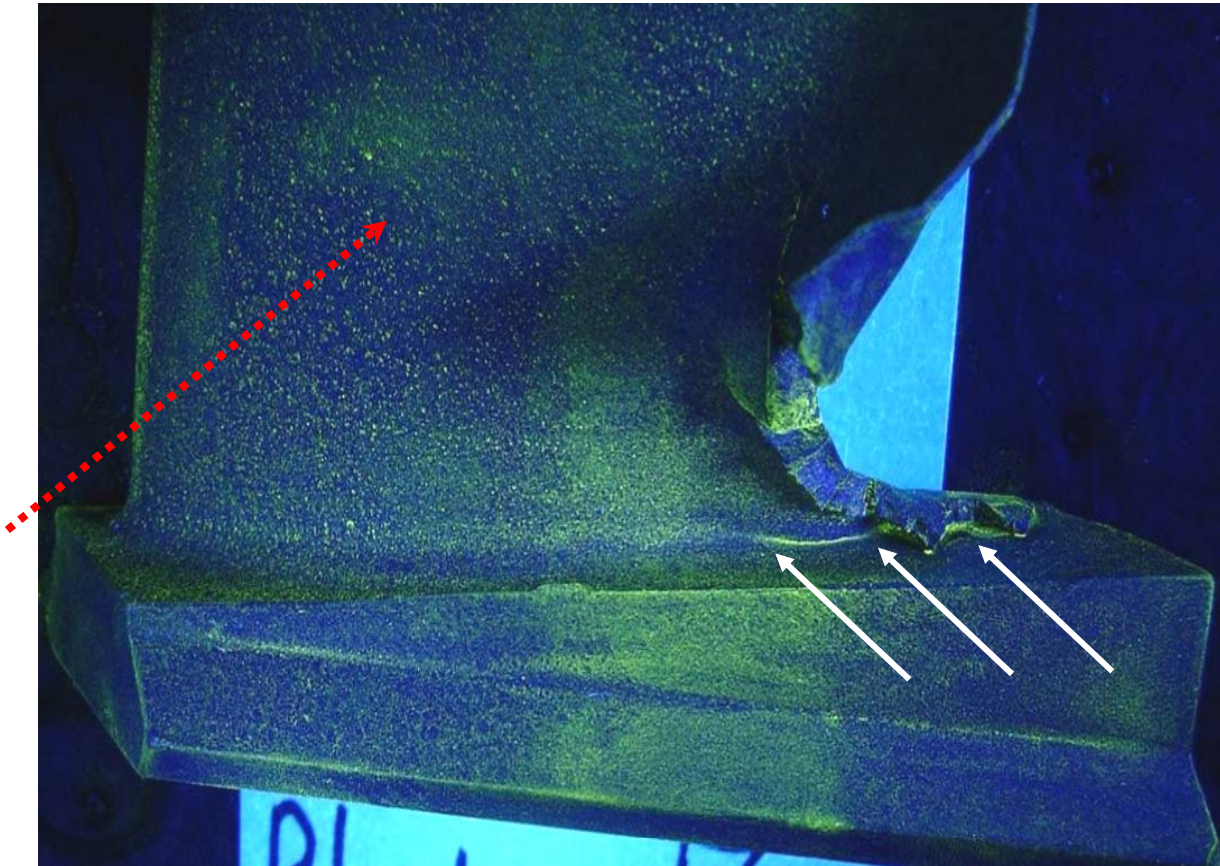
WFMT linear indication located near the root of a compressor stationary blade as shown by the white arrows (red dotted arrow shows air inlet flow direction). This type of linear indication is located away from the mechanical damage caused by the failed blades and it was observed on several of the compressor stationary blades removed for analysis

Von Mises

3.900e+004
3.575e+004
3.250e+004
2.925e+004
2.601e+004
2.276e+004
1.951e+004
1.626e+004
1.301e+004
9.763e+003
6.515e+003
3.267e+003
1.842e+001

10 psi Air Pressure

Stress Concentration

Finite element stress analysis plot of stationary compressor blade subjected to a 10 psi air pressure.

Inlet Flow Direction

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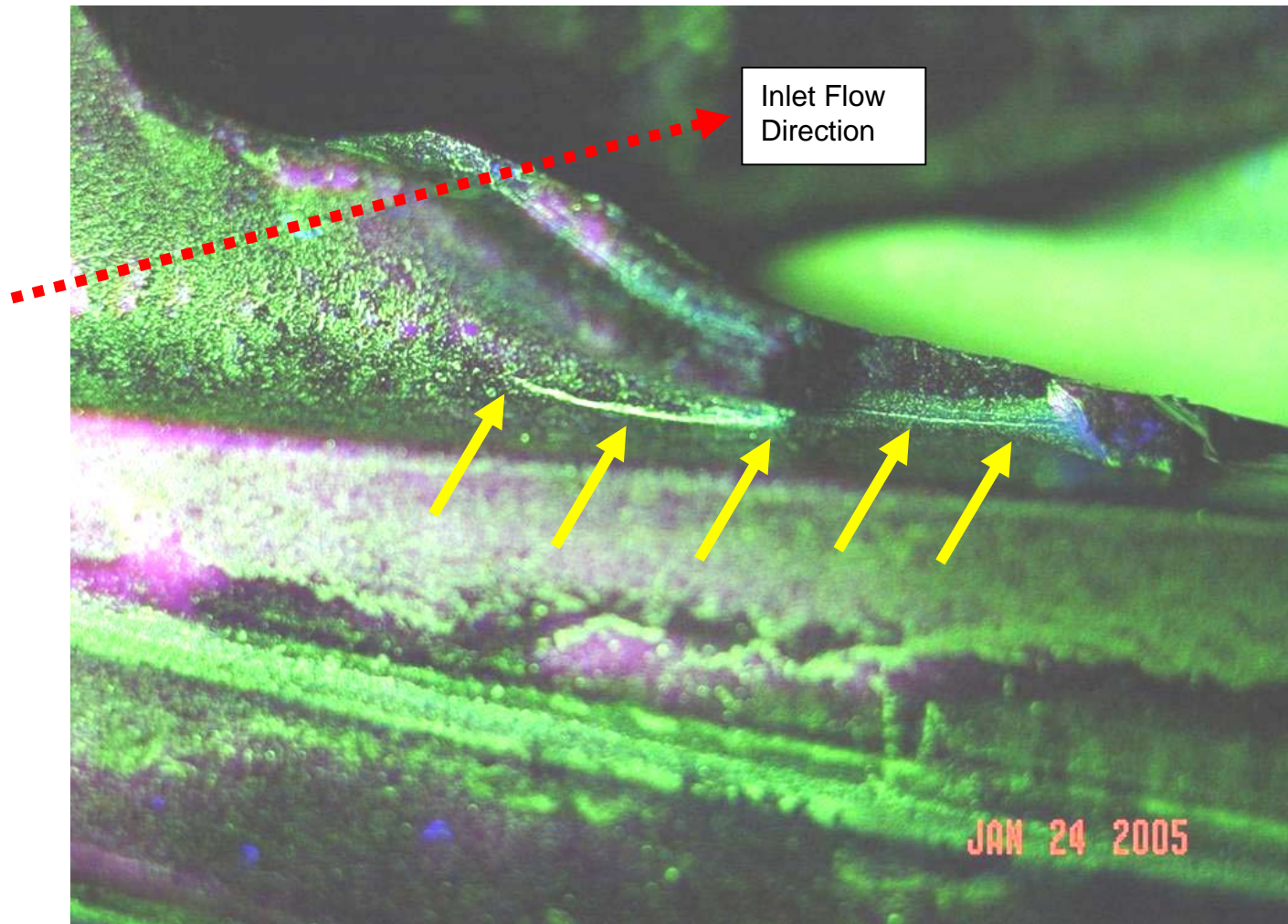
WFMT linear indication located at the root of a blade as indicated by arrows. Flaw located under mechanical damage

MODE 1 | MODE 2 | MODE 3 | MODE 4 | MODE 5
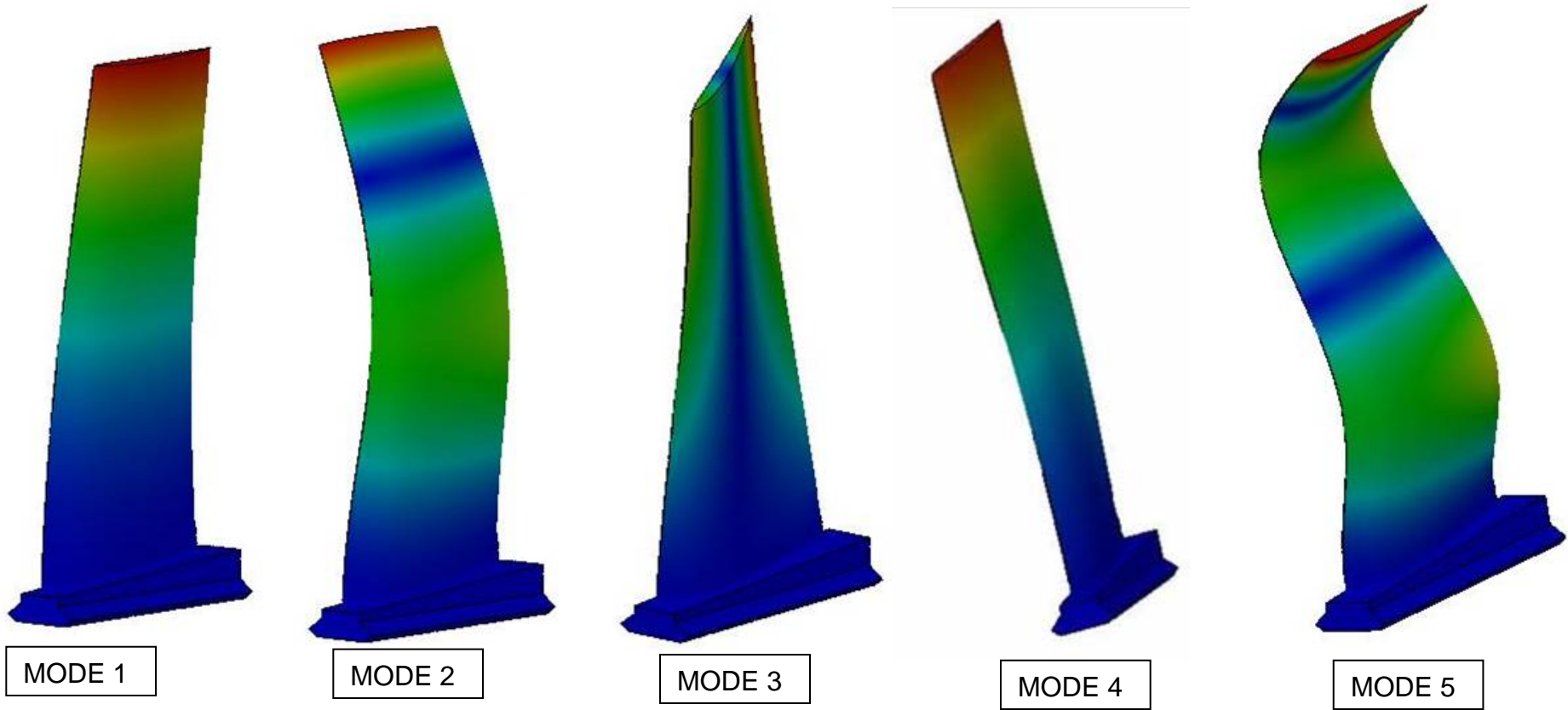
Compressor stationary blade five modes of vibration. The red color indicates the areas of maximum displacement
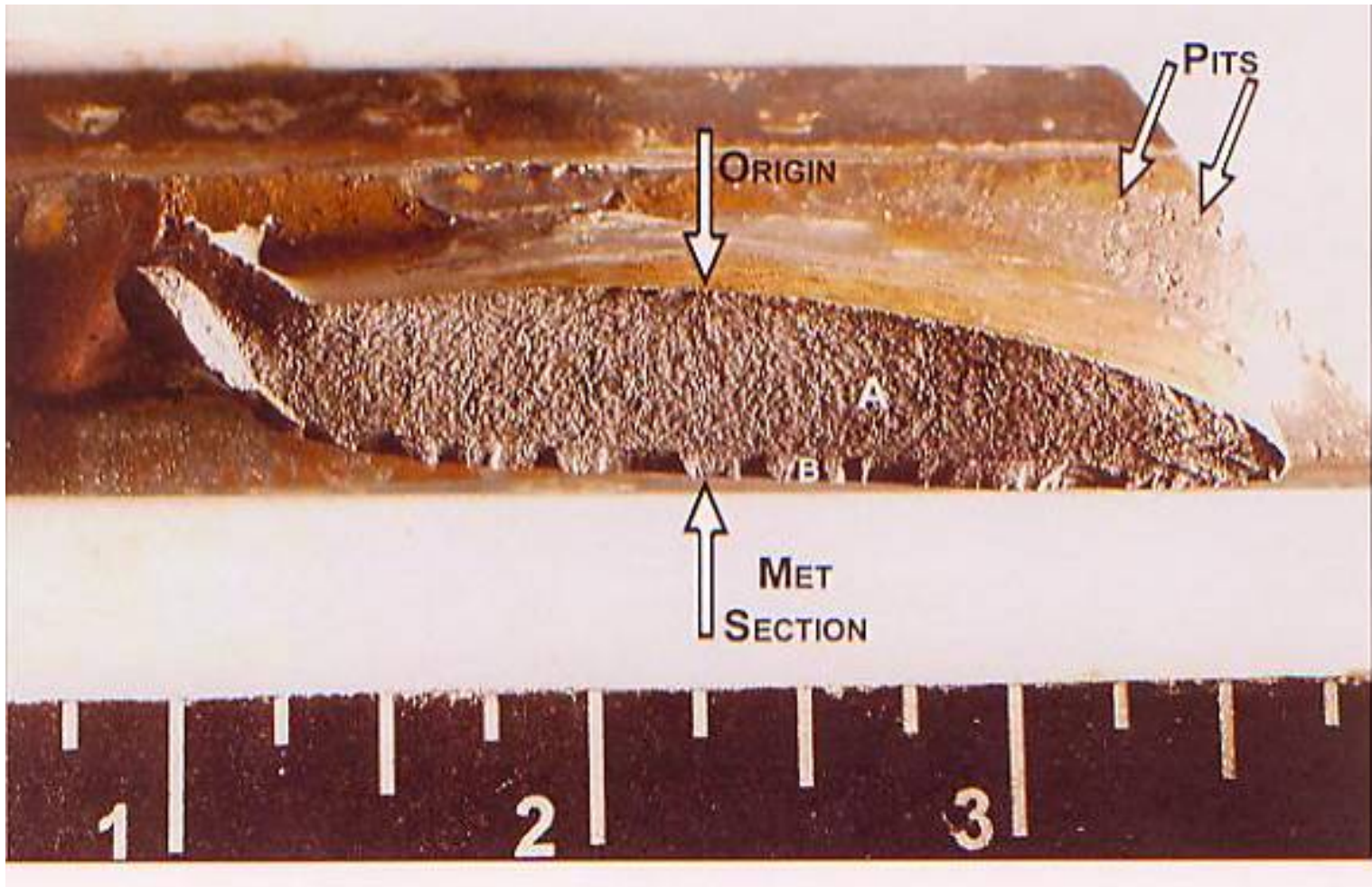
Fracture face of failed blade after solvent cleaning showing areas A and B, origin at curved face of the blade and external pits (Magnification 1.8X)
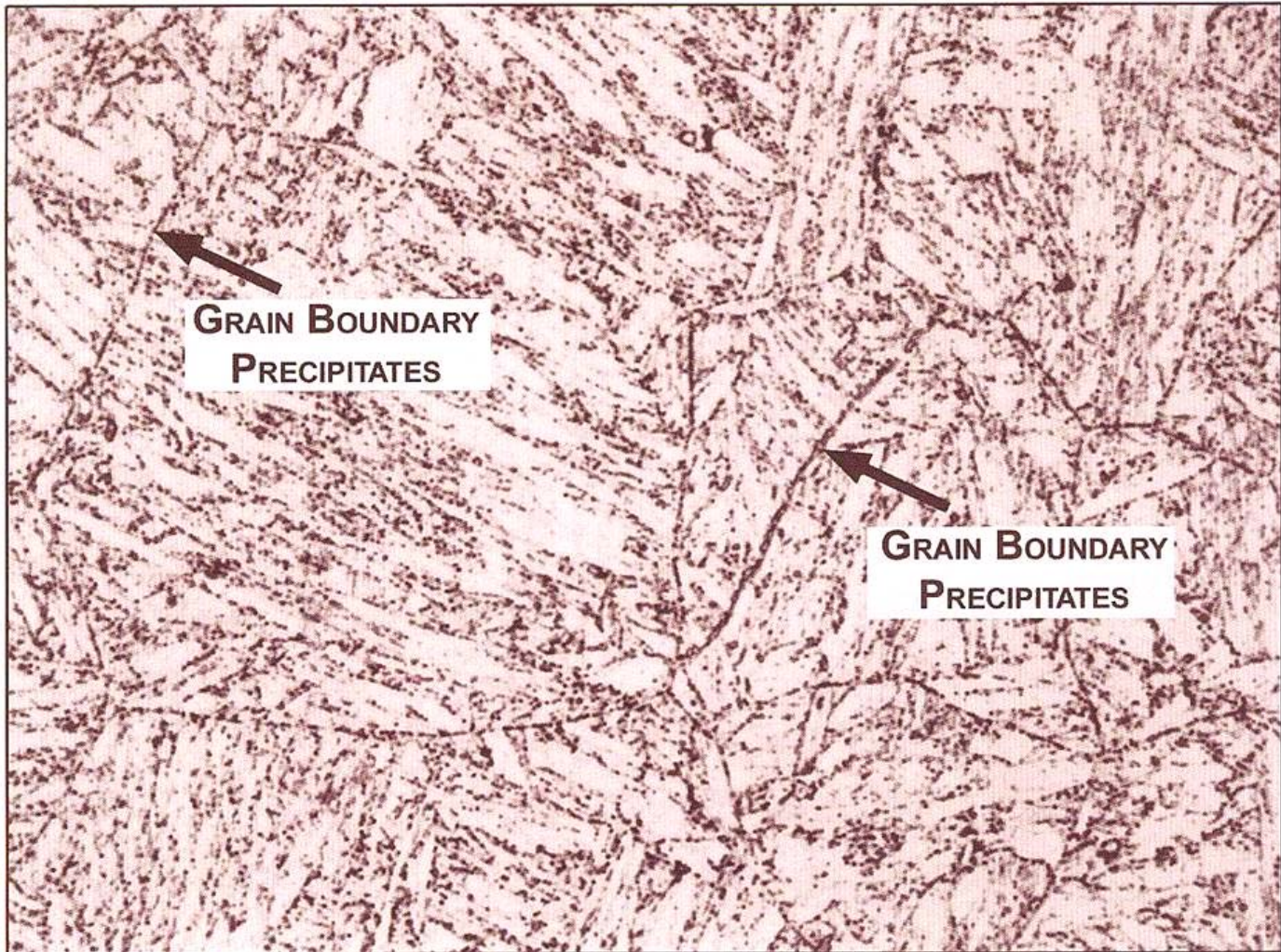
Typical microstructure of 410 SS blade material showing tempered martensite and grain boundary precipitates (Magnification 1300X)
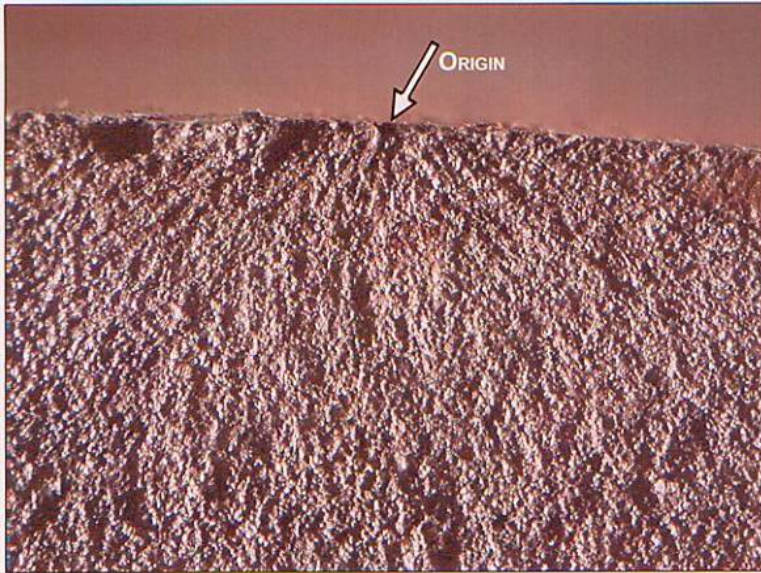
Origin area showing a corrosion pit on the fracture surface area (Magnification 16X)
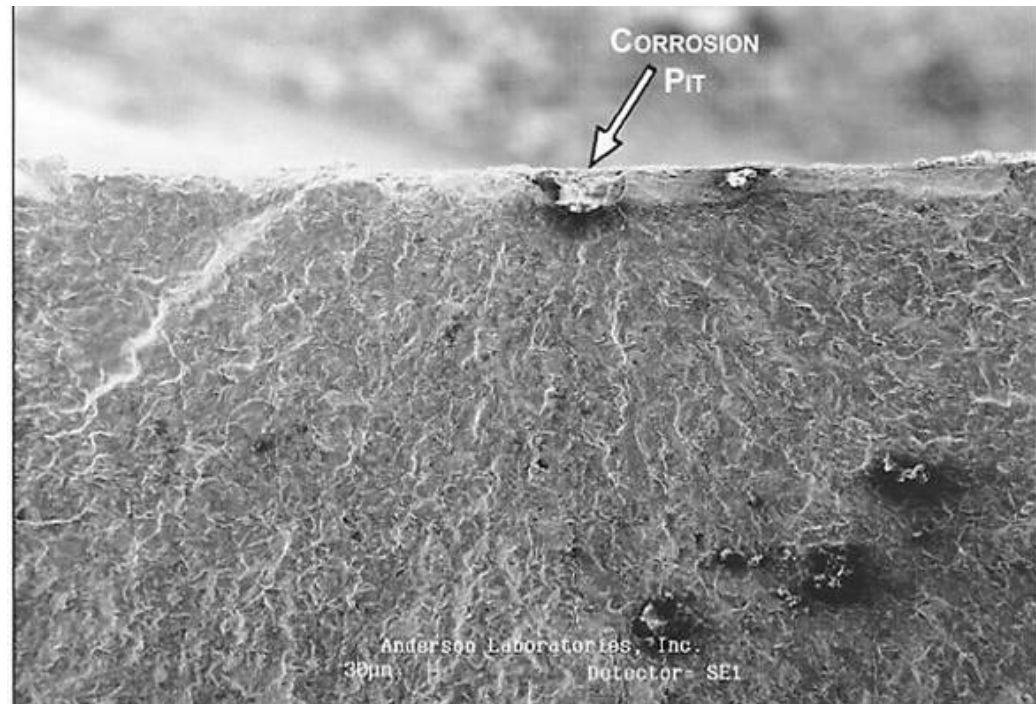
Scanning Electron Microscope (SEM) image of the pit at the fracture surface area A at 50X magnification. Corrosion and mechanical damage are also observed
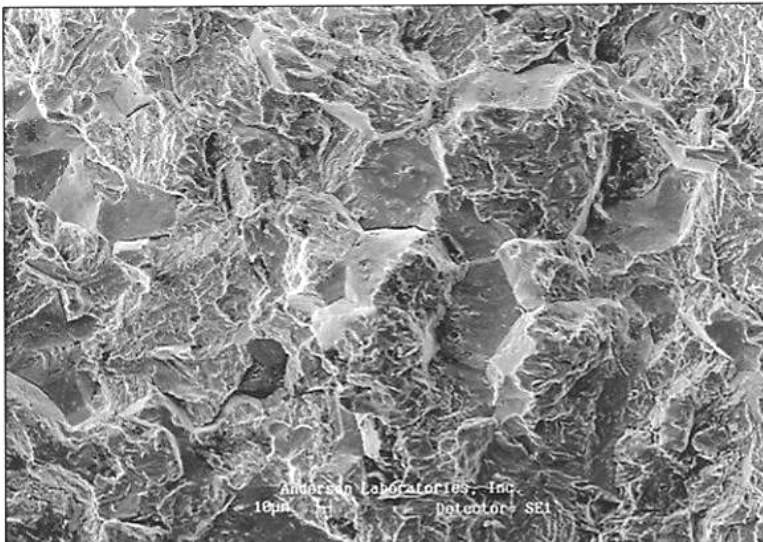
SEM image at 270X of fracture surface area A showing typical failure mode containing significant intergranular separation
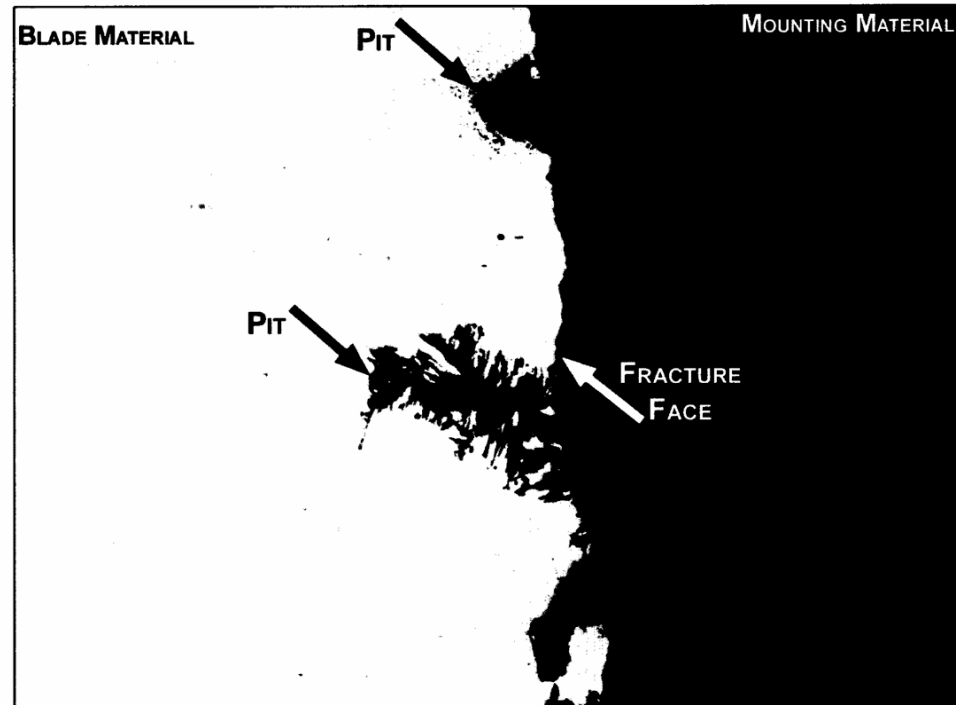
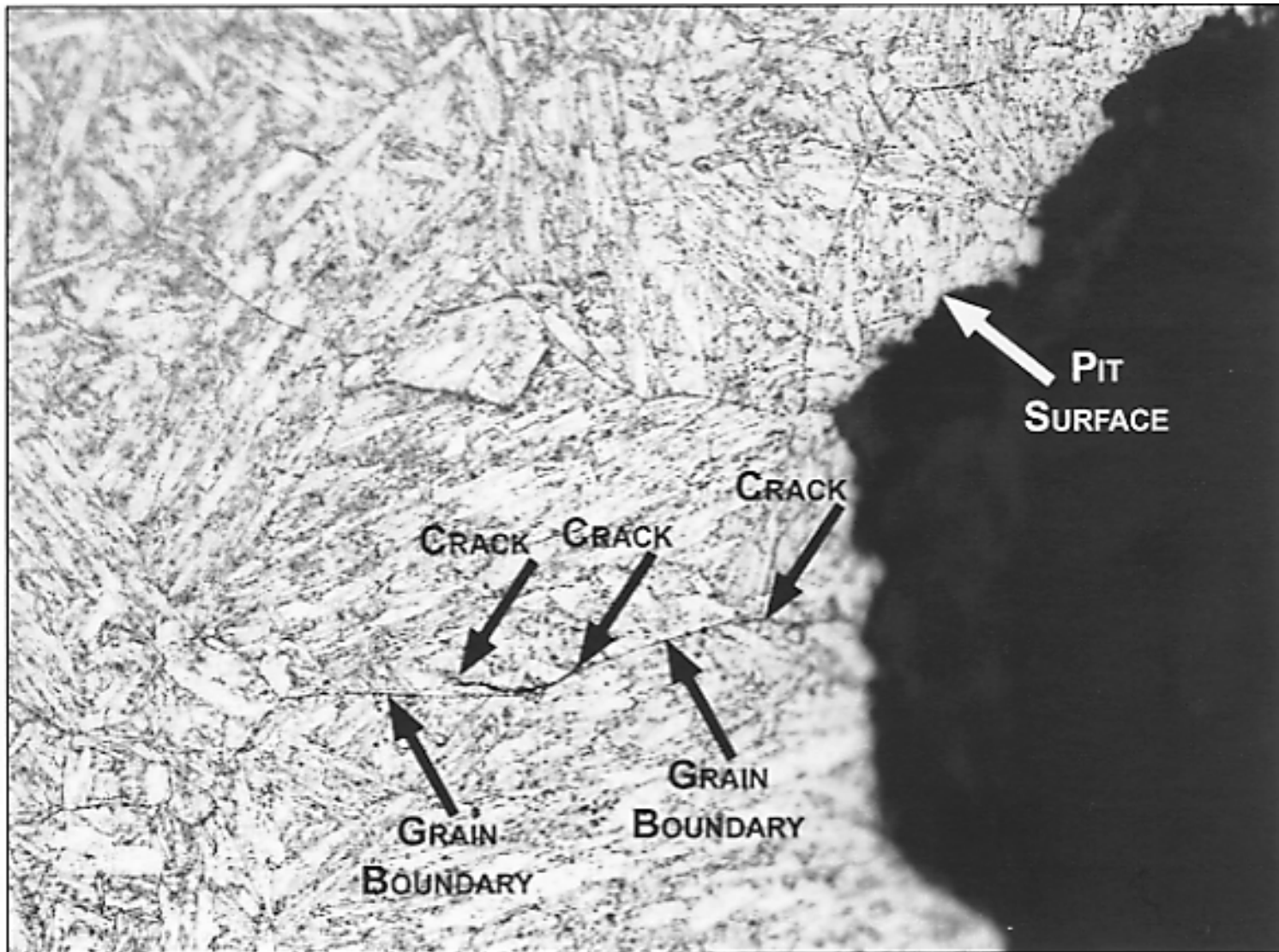Fracture face of the blade showing pits at 650X

Image at 250X of the fracture surface of the blade showing a pit and a small crack along a grain boundary extending from the bottom of a pit

SUMMARY OF FINDINGS AND RECOMMENDATIONS

Based on all the results from the three main tasks described above, it was found that the combustion turbine compressor stationary blade failure was caused by stress corrosion cracking which is a combination of three main factors, repetitive tensile stress, corrosive environment, and material susceptibility to corrosion.

It was recommended that one or more of these factors be controlled to minimize the reoccurrence of stress corrosion cracking. The utility changed the material for one that is not susceptible to corrosion in this case from 410 SS to 403 SS turbine quality steel with protective coating. Also, the utility installed a system at the intake of the compressor to control the humidity when the unit is not in service.